Preliminary Airborne Measurement Results from the Hyperspectral Polarimeter for Aerosol Retrievals (HySPAR)

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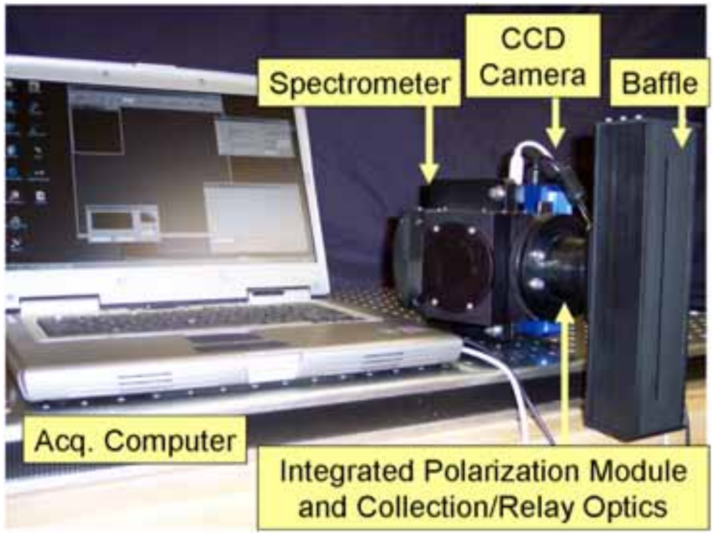
Outline

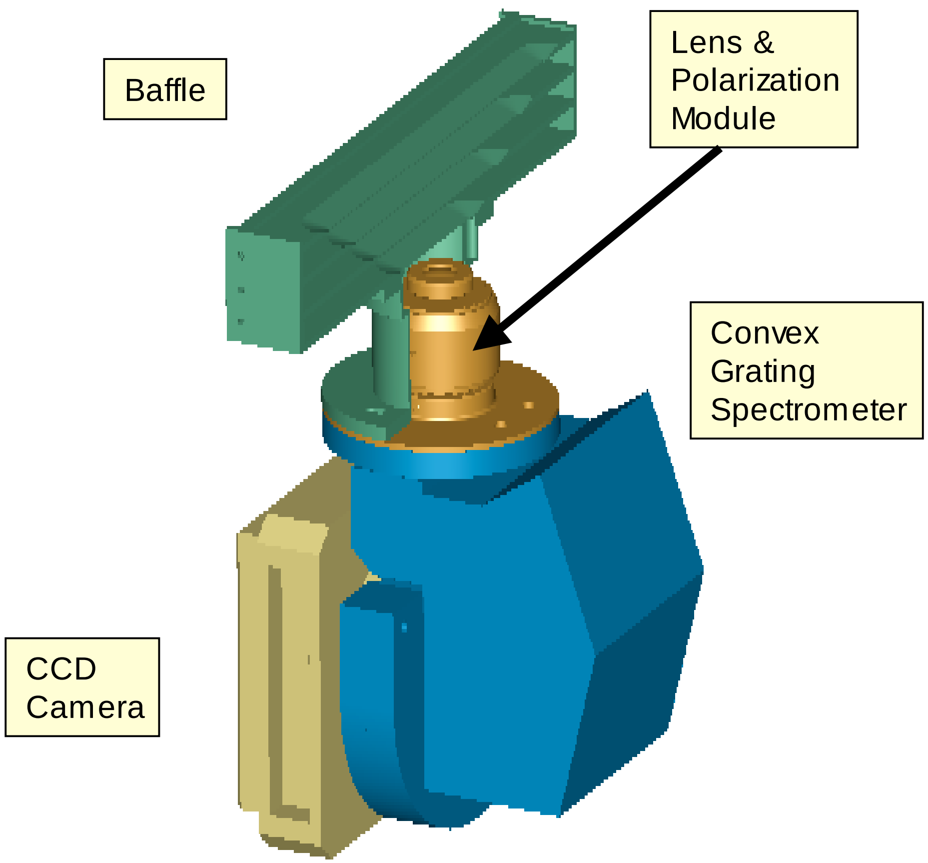
- Introduction and motivations
- HySPAR principles of operation
- Flight test results – comparison with the Research Scanning Polarimeter (RSP)

Hyperspectral Polarimeter for Aerosol Retrievals



- HySPAR is based on Aerodyne's patented Polarimetric Spectral Intensity Modulation (PSIM) technique.
- HySPAR sensor developed and built under SBIR Phase 1&2 funding from NASA LaRC. Technical monitors: Lamont Poole and Chris Hostetler.
- Currently funded by NASA Goddard to perform measurement validations and participate in flight tests with LaRC sensor suite. COTR: Parminder Ghuman. LaRC technical monitor Chris Hostetler.

HySPAR



200 x 300 x 400 mm, 5.5 kg

- Integration time: AGC
- Spectral characteristics:
  - Range: 480-960 nm
  - Raw res.: 0.9 nm
  - Stokes inversion res.: 20 nm nominal
- Angular sampling: 120^{o} FOV, 512 pixels, 12 mrad IFOV.
- Raw SNR/spectral bin: >150:1 (@0.1AOT, 100^{o} scat. Angle, 1s int. (Uplook).
- NeDoLP: ~0.4% @ 80% full well, goal 0.1%

NASA Science Motivations

- Increase both capabilities and simplicity of spectropolarimetric aerosol retrieval sensors.
  - Full Stokes (including circular polarization) snapshot hyperspectral polarimetry.
  - Compact, simple, low cost design.
  - Potential for more robust retrievals over land due to denser spectral coverage – background removal.
- Potentially enable new science findings.
  - Improved temporal resolution of aerosol dynamics, full multiangle spectropolarimetric measurement in ~1 second.
  - Full Stokes capability improves diagnosis of non-spherical scatterers.

Snapshot Spectropolarimetry

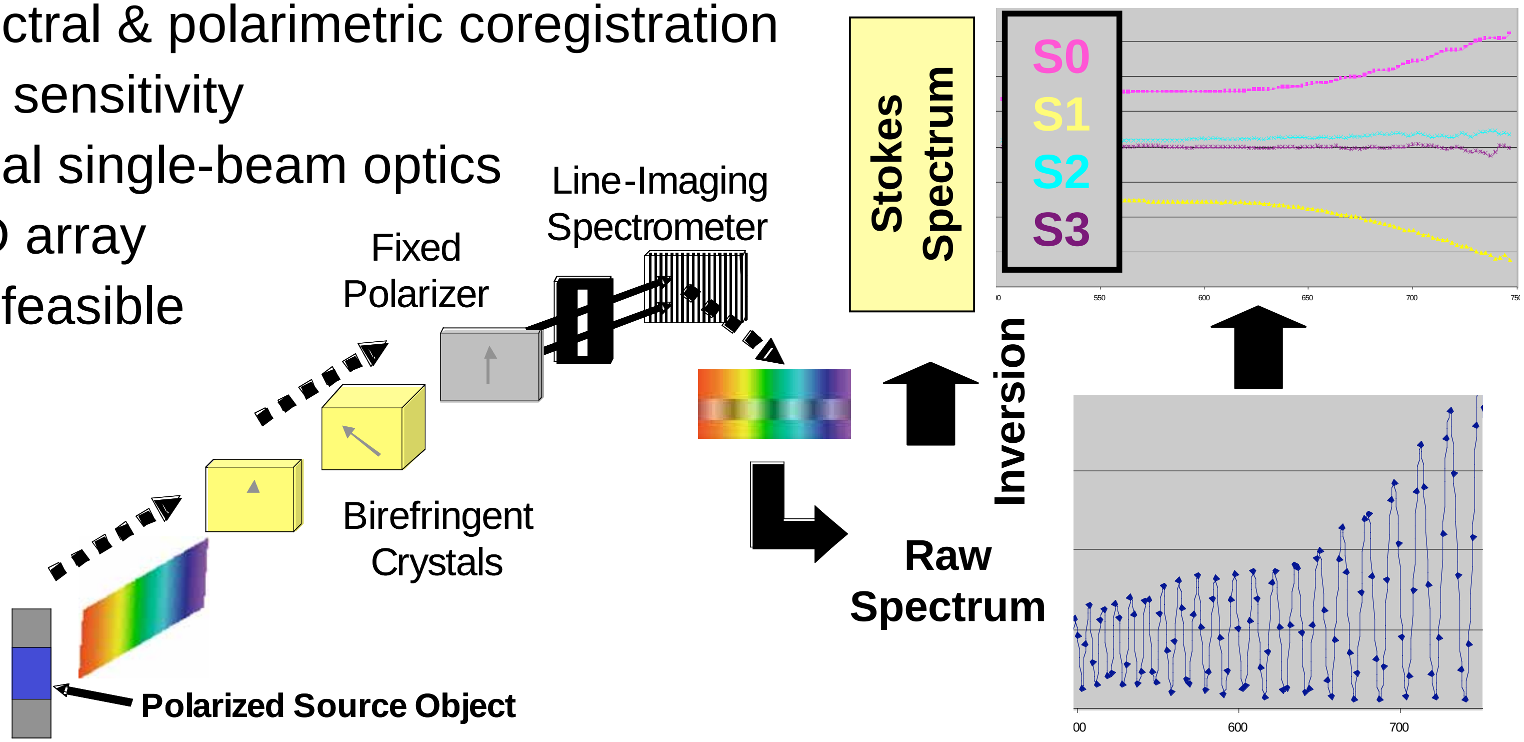
- Current Art Polarimetry – Three classes
  - Multiplex-in-time. e.g. rotating waveplate.
    - *PROBLEM*: Misregistration-in-time.
  - Multiplex-in-space. e.g. pixel masks.
    - *PROBLEM*: Misregistration-in-space.
  - Parallel. e.g. Beamsplitting w/ multiple analyzers.
    - *PROBLEM*: Costly; alignment challenges.
- Misregistration artifacts masquerade as polarization
  - thereby defeating polarimetry's appeal...
  - or circumscribing it to temporally static or spatially uniform scenes.
- PSIM Based Imaging SpectroPolarimetry Offers:
  - *Single snapshot* multi-angle spectro-polarimetry
  - *Inherently registered* spectrum and polarimetry
  - Full Stokes spectropolarimetry (including circular polarization)
  - Single focal plane detector
  - Single beam optics
  - Compact, rugged design

HySPAR Principles of Operation

Polarimetric Spectral Intensity Modulation (PSIM*)

* U.S. Patent 6,490,043, Kebabian (Aerodyne)

- Single snapshot (dynamic scenes)
- Perfect spectral & polarimetric coregistration
- Full-Stokes sensitivity
- Conventional single-beam optics
- Single CCD array
- UV-thru-IR feasible

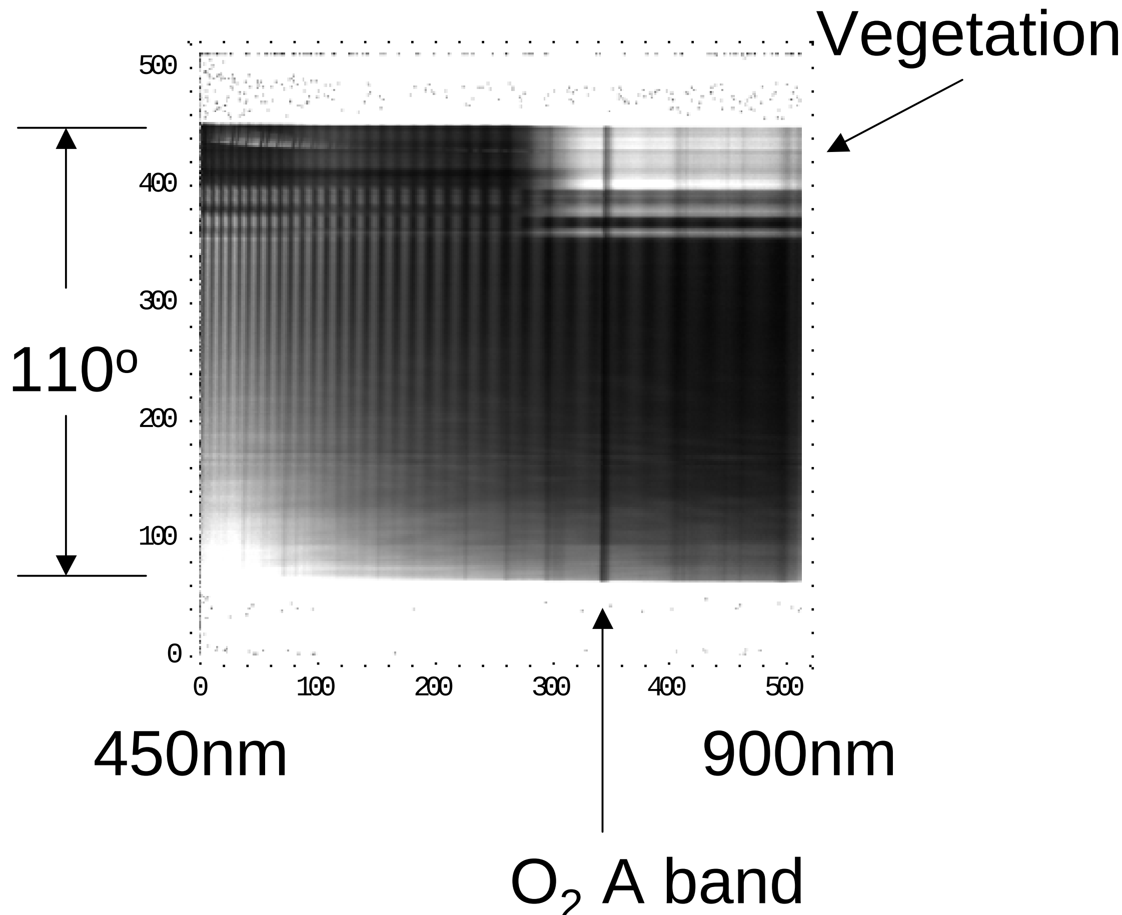


Novel configuration *instantaneously* induces polarization-dependent interference fringes upon the measured intensity spectrum.

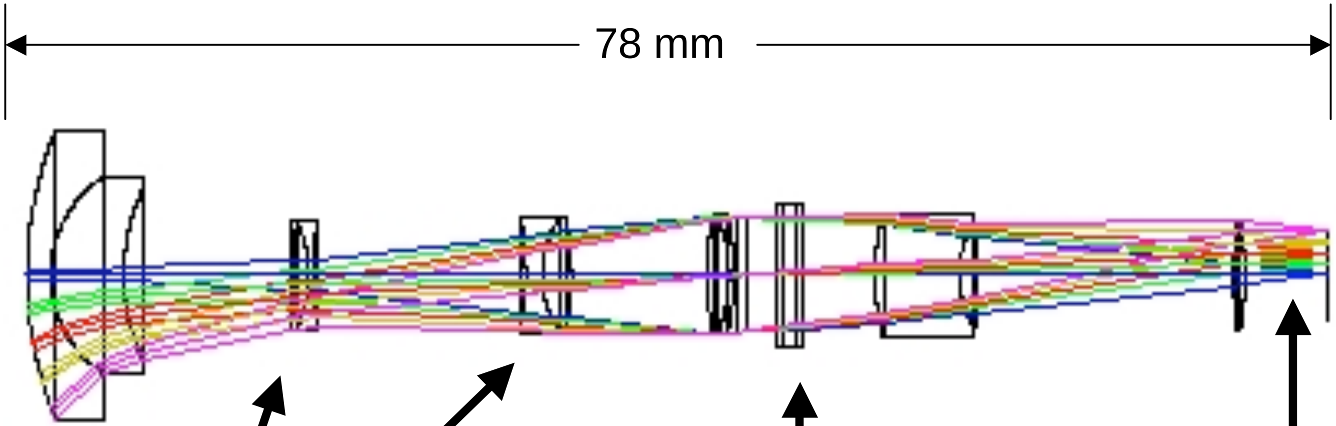
Consequently, the full Stokes spectrum can be retrieved from the modulated intensity spectrum based on the fringe patterns.

HySPAR Raw Data

Data taken uplooking in solar principal plane



Final Design: 2.2 mm, f/4

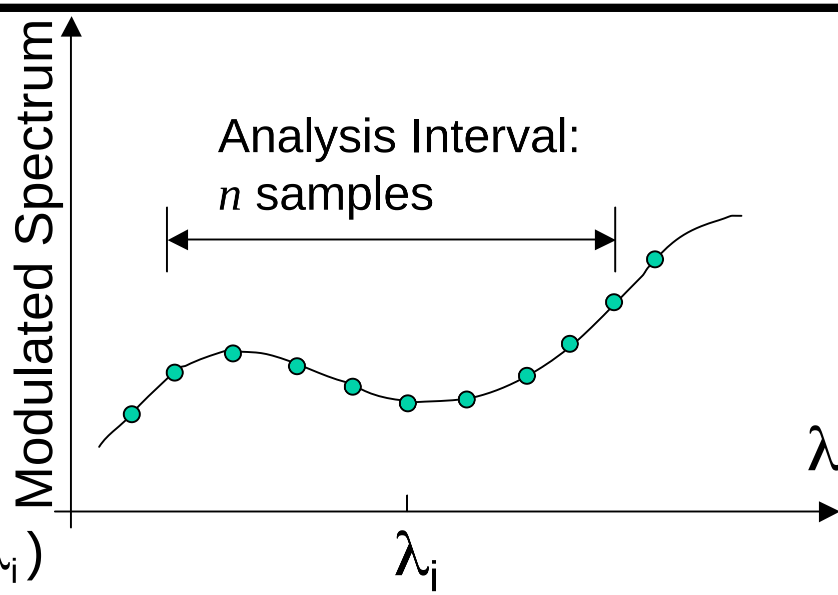


Polarization Module
Nearly collimated

Very nearly telecentric for coupling to imaging spectrometer. Exit pupil is –675 mm from image surface.

120 deg FOV but
small angles of incidence throughout. Price: increased length over a conventional fish-eye.

Model for Stokes Retrieval



Data Vector, $\mathbf{d}(\lambda_i)$

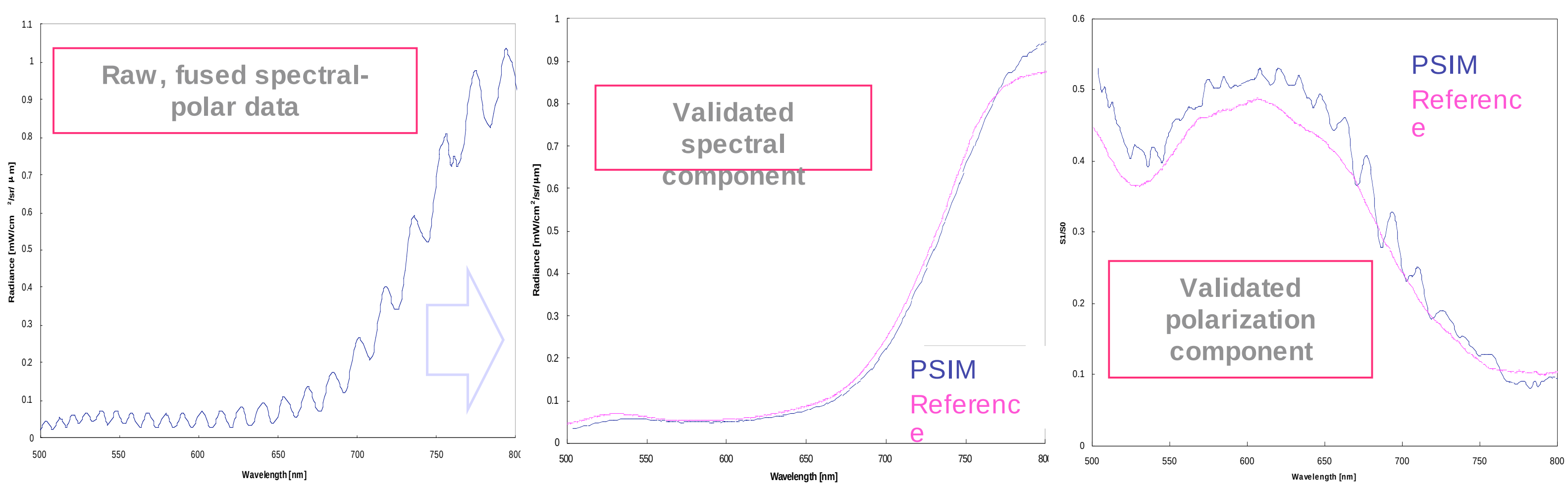
$$\begin{bmatrix} d_{i-\frac{n-1}{2}} \\ \vdots \\ d_i \\ \vdots \\ d_{i+\frac{n-1}{2}} \end{bmatrix} = \begin{bmatrix} m_{1,1} & \cdots & m_{1,8} \\ \vdots & & \vdots \\ m_{2n+1,1} & \cdots & m_{2n+1,8} \end{bmatrix} \bullet \begin{bmatrix} \mathbf{s}_{\text{constant}} \\ \cdots \\ \mathbf{s}_{\text{linear}} \end{bmatrix}$$

Incident Augmented StokesVector, $\mathbf{s}(\lambda_i)$

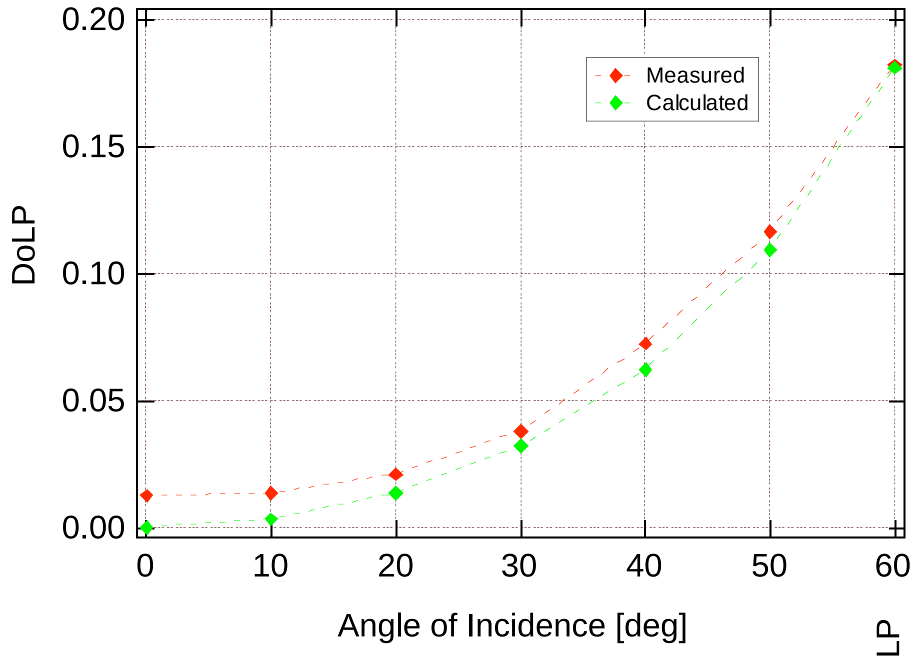
System Matrix, $\mathbf{M}(\lambda_i)$

Spectral Resolution

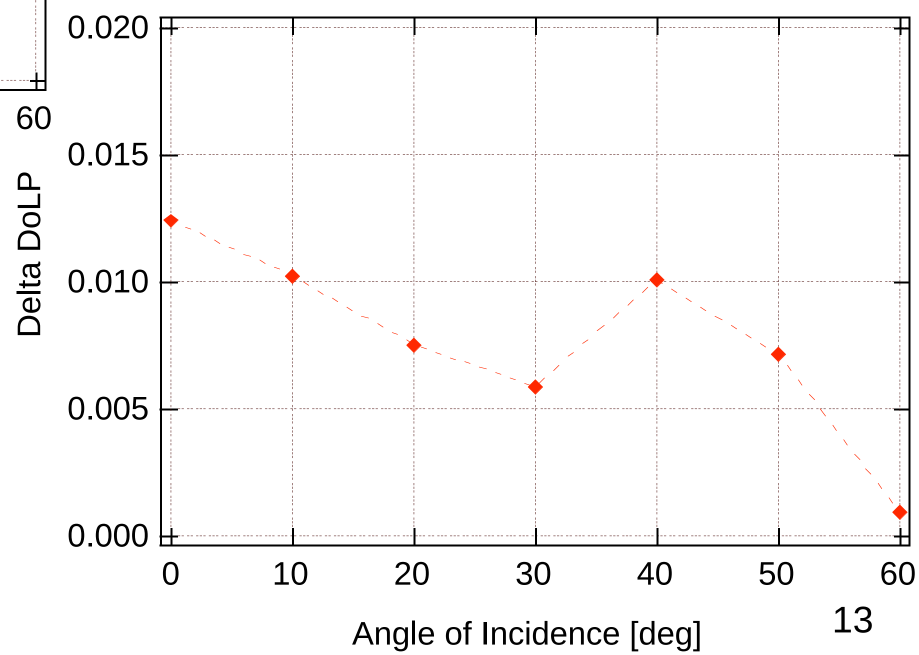
- Actual spectral resolution is “somewhat” better than the width of the analysis window.
  - Window is shifted in 0.9 nm increments as opposed to non-overlapping windows.
  - Response is therefore akin to a moving average.
- Example: for a 20 nm analysis window, a moving average will pass a 50% slope across the window at 50% amplitude.
- Analogy is not exact for HySPAR and the signal subspace of the fringes must be considered as well.



DoLP Validation



- Initial DoLP validation using tilted dielectric plate (Pyrex).
- Refractive index and thus Fresnel transmittance are well known.
- Measurement made at center of field.
- Center wavelength: 500 nm



Achieving 0.5-1% polarimetric accuracy in this case

Flight Testing Results

Flight Testing

- Megacity Initiative: Local and Global Research Observations (MILAGRO).
  - International research team performing measurements of pollutants, trace gases and aerosols in the Mexico City and Veracruz environs.
- March 2006 flights w/ HSRL, LAABS, and HySPAR on a single platform (King Air, 9 km alt.)
  - HSRL: High Spectral Resolution Lidar (LaRC)
  - LAABS: Langley A-Band Spectrometer (LaRC)
  - HySPAR: (Aerodyne)
- Performed coordinated flights with Research Scanning Polarimeter (RSP) flying aboard the J31 aircraft, 4.6 km alt.

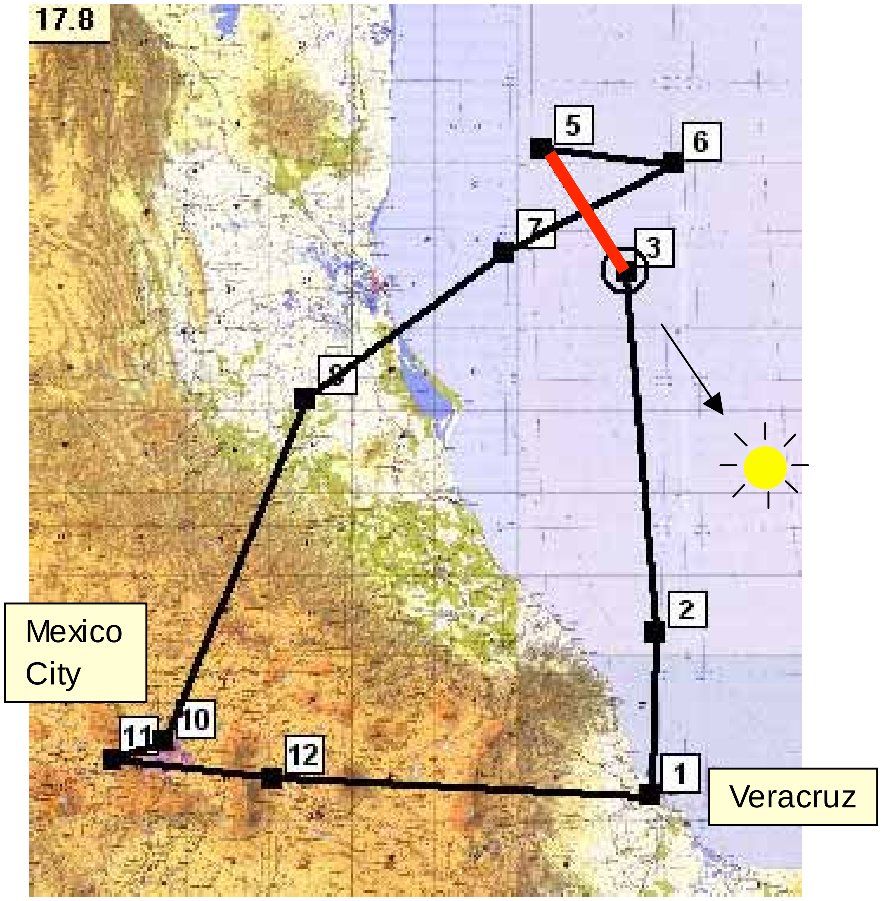
Research Scanning Polarimeter

- Designed & built by SpecTIR Corp. (Ed Russell), Brian Cairns NASA/GISS PI.
- NASA heritage multiband polarimeter (linear polarization).
- Six boresighted refractive telescopes
- Scan mirror assembly scans through +/-60 deg.
- Wavelengths (BWs): 410(30), 470(20), 550(20), 670(20), 850(20), 960(20), 1590(60), 1880(90), 2250(120) nm.
- IFOV 14 mrad.
- ~0.1% polarization accuracy.

Flight Testing Challenges

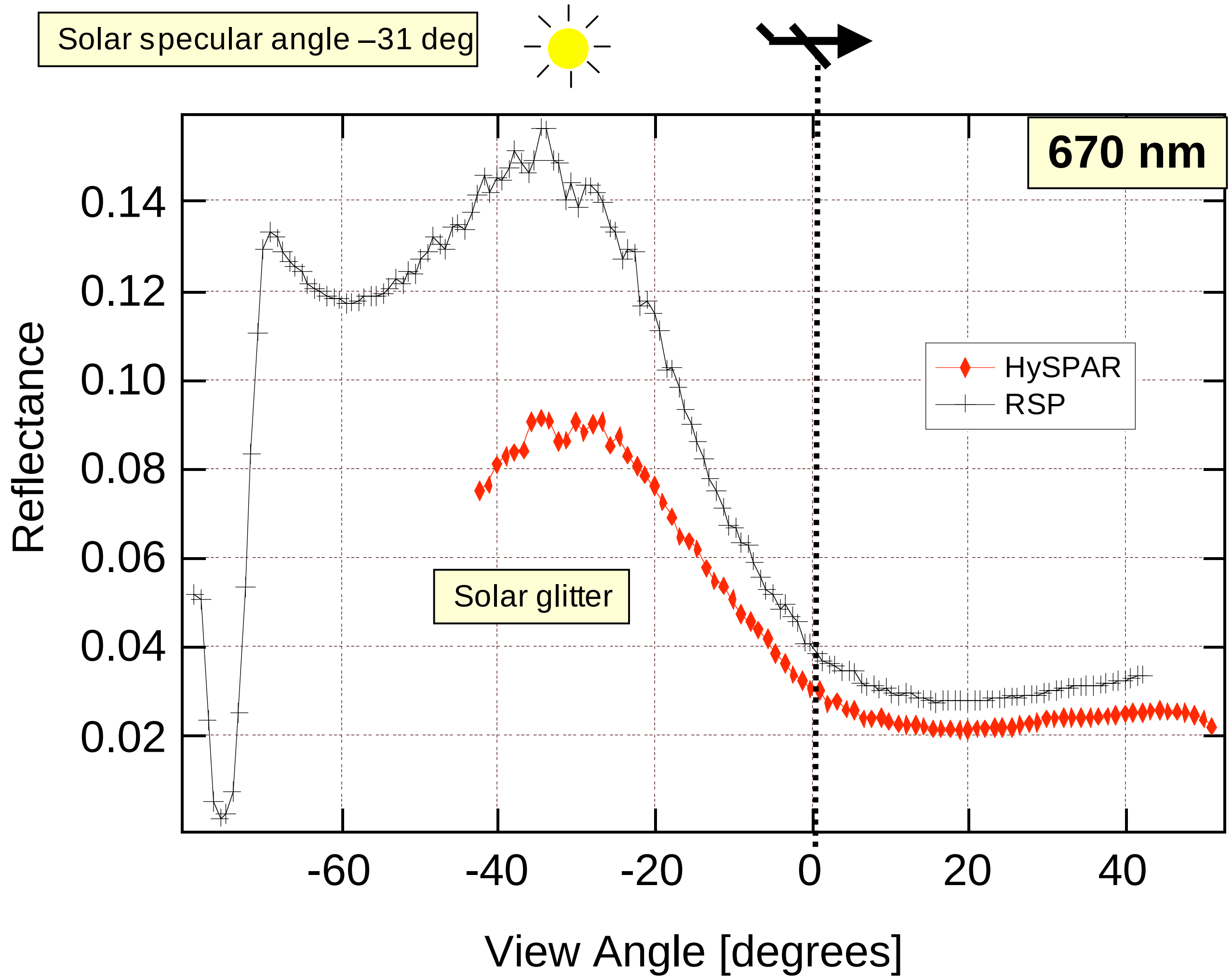
- Pressurized cabin necessitates looking through a window.
  - Fresnel transmittance
  - Potential stress birefringence
- Solution:
  - Used uncoated BK7 window to avoid uncertainty about coating condition.
  - Designed window and mount to minimize stress. For HySPAR this yielded a narrow slot-like window.
- Thermal sensitivity of birefringence and CTE causes spectral fringes to shift and broaden.
  - Variable temperature of crystals due to cold window.
- Solution:
  - Developed inversion algorithms capable of inferring calibration from scene data.

B200 Flight Path



- Coordinated segments with J31 (RSP)
- Segment 3-5: solar principle plane, data comparison that follows.
- Segment 6-7: cross principle plane

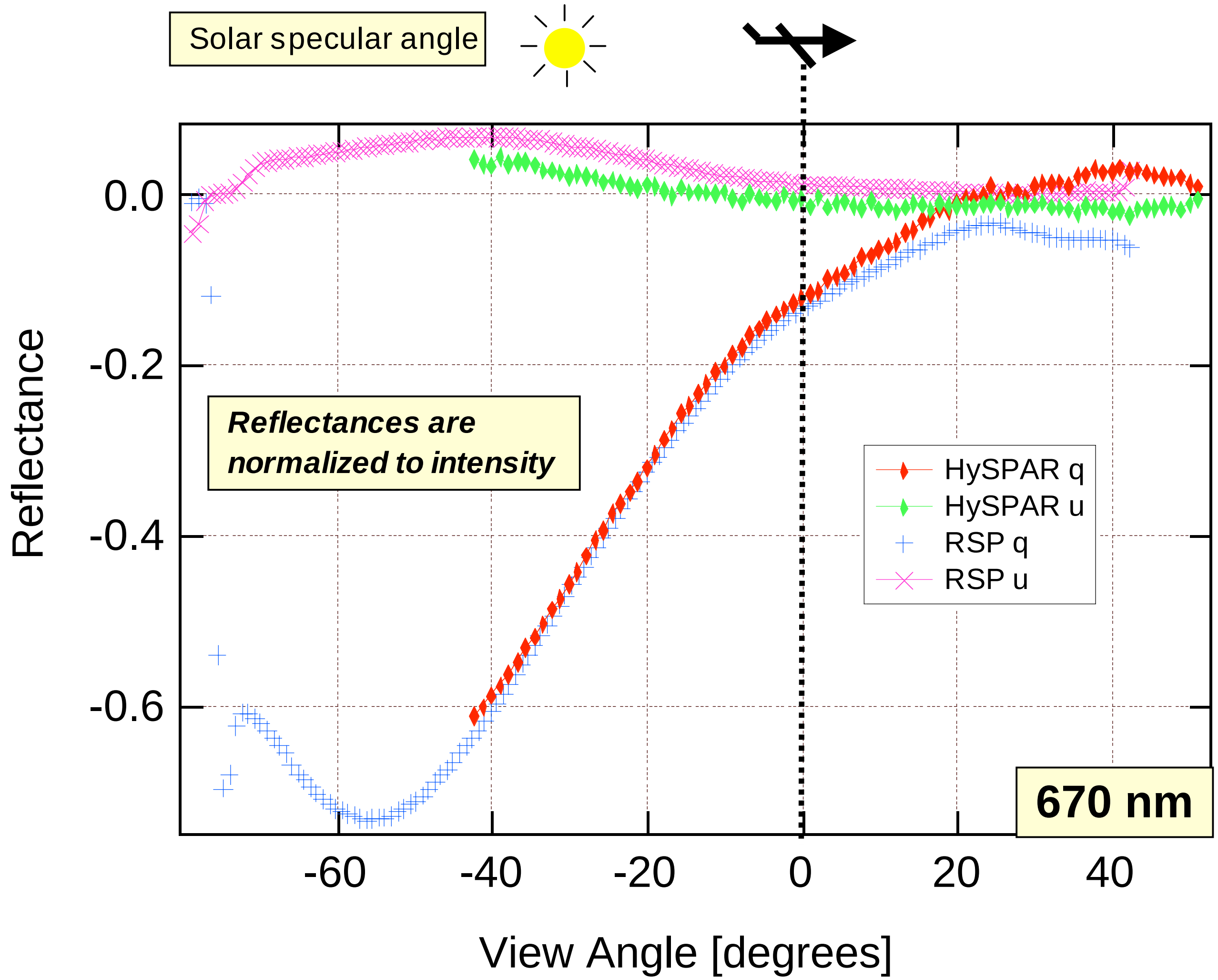
HySPAR/RSP Unpolarized Reflectance



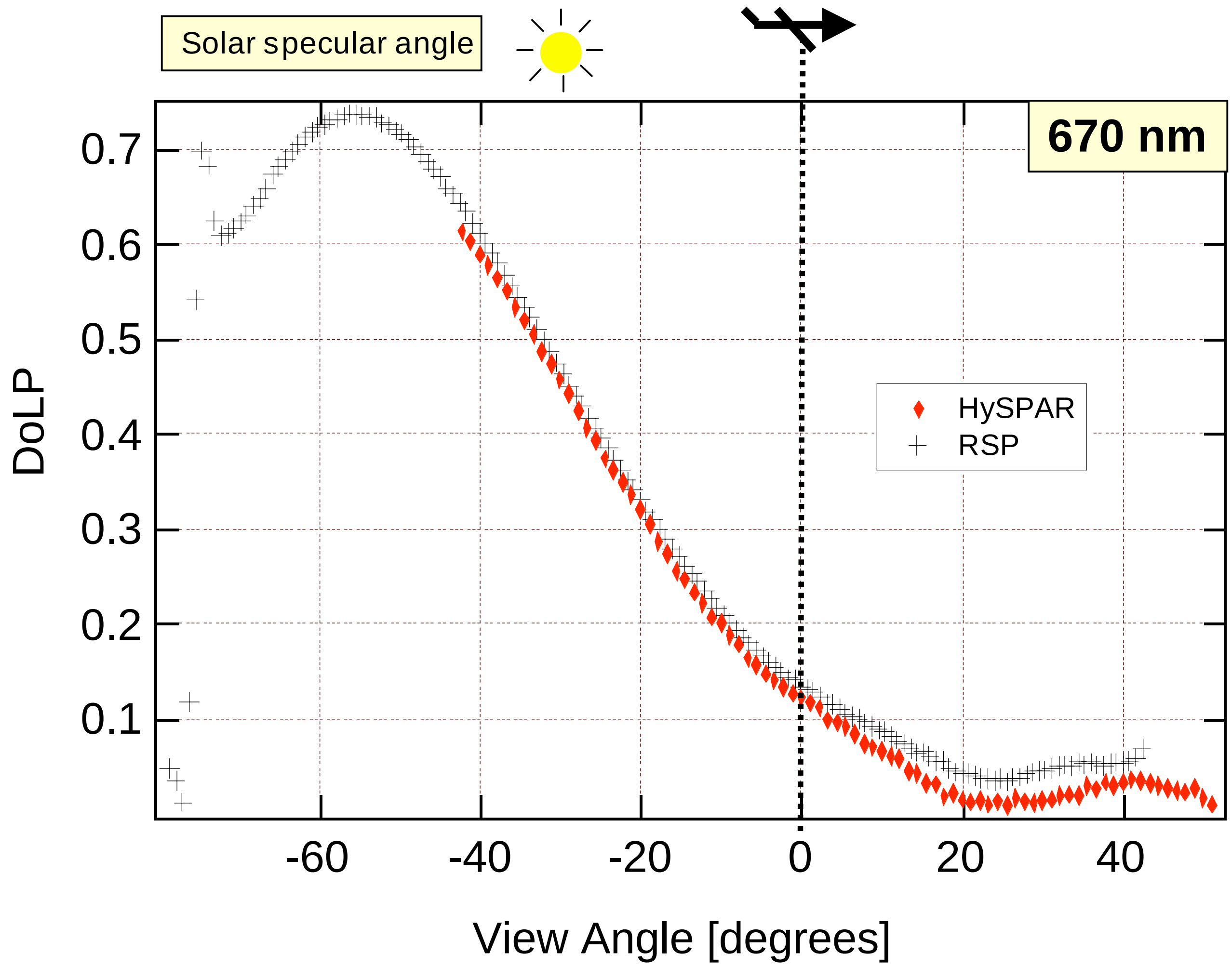
- Data taken over water in the solar principal plane.
- Altitudes:
  - HySPAR 9000 m
  - RSP 4600 m
  - HySPAR should probably read higher than RSP.
- Discrepancy is assymmetrical about nadir so is not likely due to window.
- Cox-Munk glitter analyzed wrt IFOV and potential pointing error but does not appear to explain difference.
- Stray light rejection differences between instruments possible but not likely.
- Radiance cal?

View angle is nadir angle ALONG TRACK

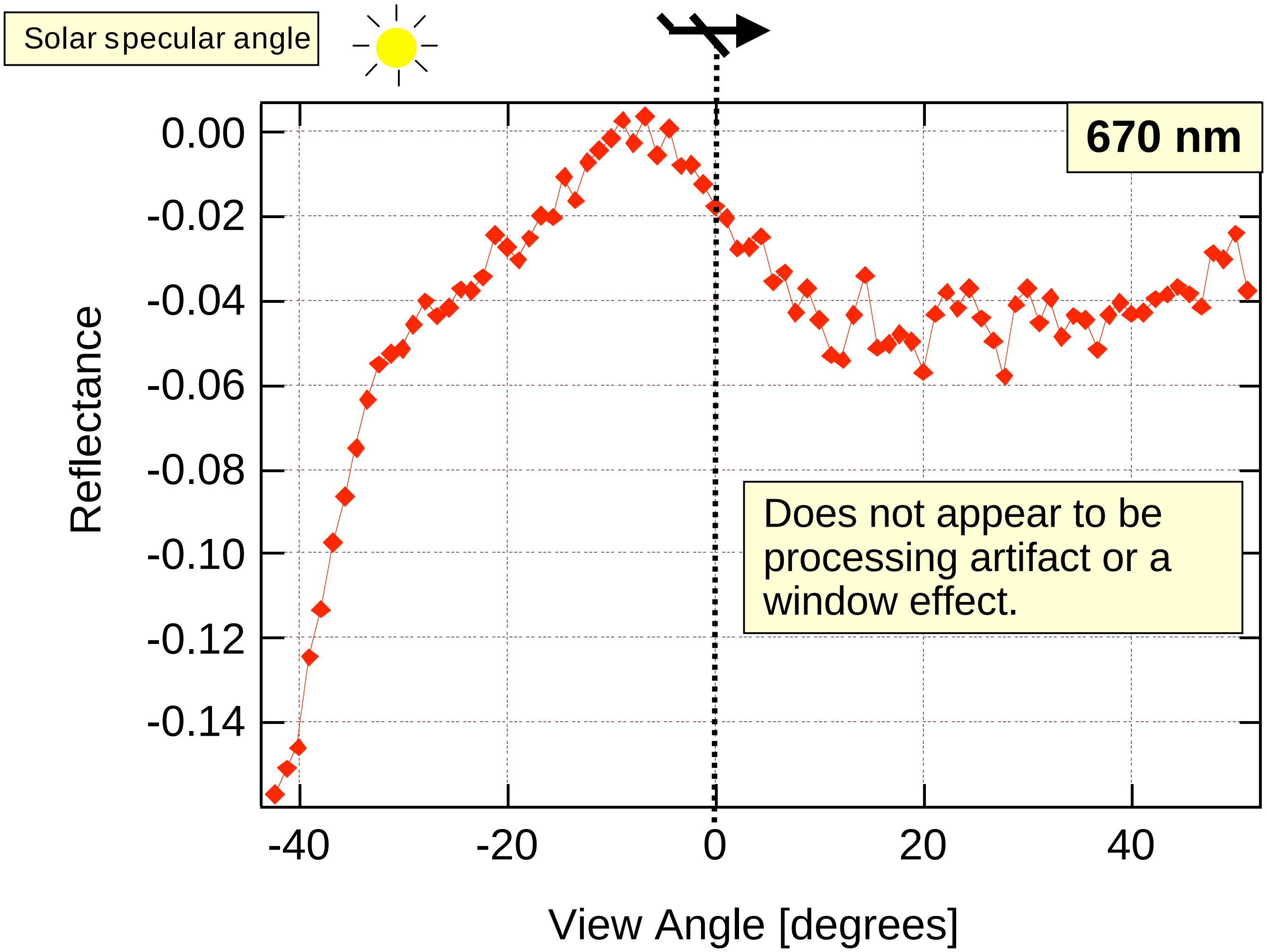
Polarized Reflectances



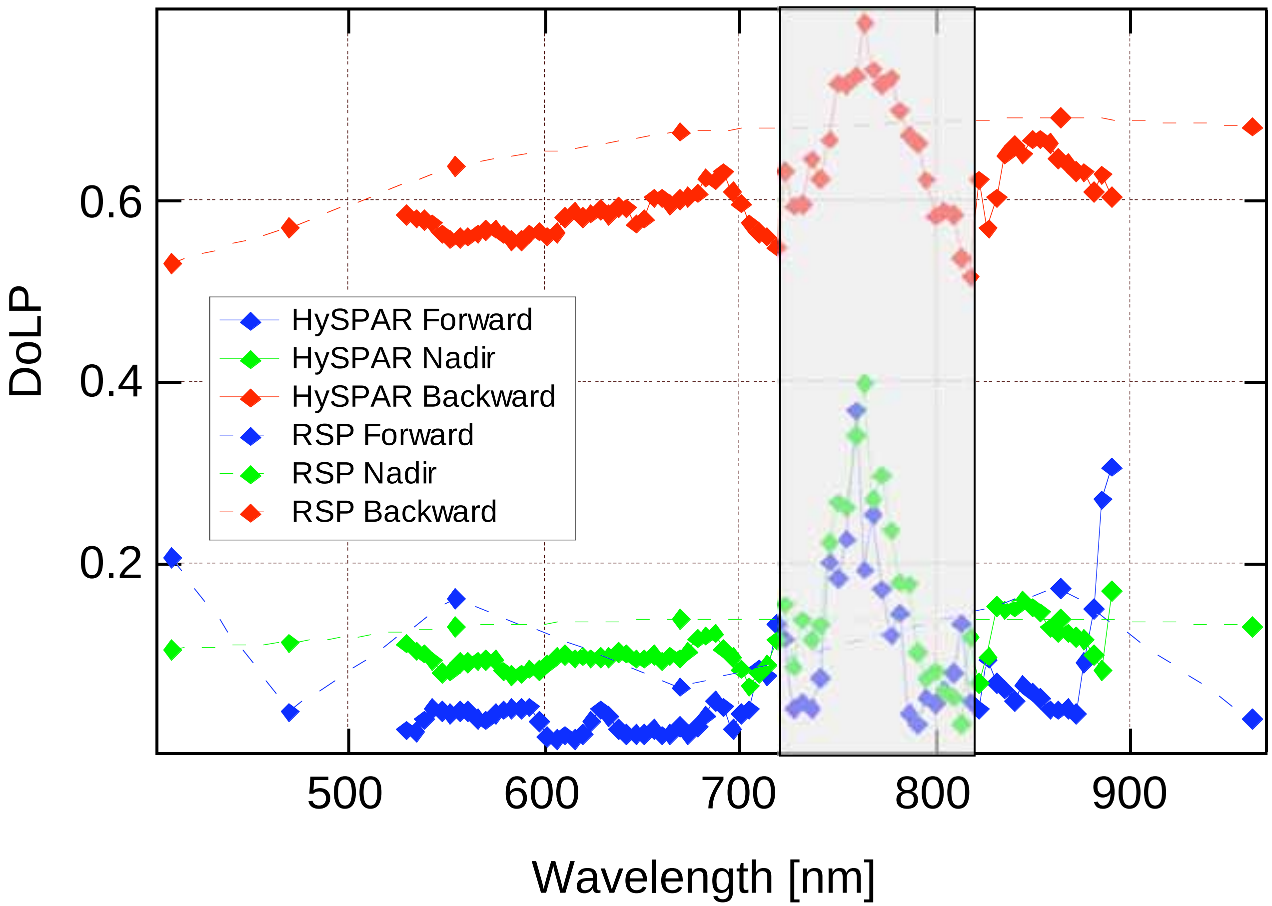
Degree of Linear Polarization



HySPAR Circular Polarization



DoLP Spectra



- **Shaded area indicates region around Oxygen band in which the HySPAR inversion model does not presently account for the underlying degree of spectral variation.**
- **This is conceptually straightforward to remedy but it has not yet been implemented.**

Conclusions and Future Work

- Largely successful comparison to RSP
  - Excellent polarized reflectance agreement
  - Need to determine cause of unpolarized reflectance discrepancy
- Harvest HySPAR/HSRL/LAABS MILAGRO database
  - More complete comparison with RSP
  - Investigate and characterize the prevalence and causes of circular polarization signal.
- Develop retrieval algorithms that exploit unique HySPAR capabilities
  - Elliptical polarization for non-spherical aerosols.
  - Dense Stokes spectrum (over-land background removal).
- Exploit fusion of active/passive data (HSRL/HySPAR/LAABS).